Energy and Exergy Analysis of Solar Photovoltaic/Thermal Hybrid Air Collector System

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Abstract: Solar PV-T is the hybrid system, combining solar PV and solar thermal system which provides both electricity and thermal energy simultaneously. This paper presents an approach to study the thermal and electrical characteristics of the collector. Inlet and outlet temperature of air, thermal, electrical and overall efficiencies of the system are measured under the meteorological conditions of Bhopal, M.P, India. Exergy analysis is also carried out in this paper. Exergy is the available low grade energy which is available for conversion. It is found that the overall efficiency is varies between 30-60% and the maximum exergy efficiency is found to be 9.72%. The results indicate that it is possible to obtain more energy per unit of surface compared to the thermal and the photovoltaic solar collectors separately.

Keywords: **Electrical Efficiency, thermal efficiency, exergy, energy, solar PV/T, solar energy**

1. INTRODUCTION

Solar energy is one of the most important source of renewable energy that world needs. After the conversion of electrical energy more than 80% of the absorbed is again dumped back into the surroundings. The major applications of solar energy can be classified into two categories: Thermal system (T) and Photovoltaic system (PV) cell. In conventional photovoltaic system, high incident solar radiation on (PV) panel should give high electrical output. However, high incident will increase the temperature of the solar cells and that will decrease the efficiency of the panel. With every increase in temperature by 1°C corresponds to the decrease in efficiency by 0.5%. Moreover high temperature of a solar cell for a long time also shortens its service life. Therefore, to achieve both higher cell efficiency and higher electrical output we must cool the cells by removing the heat in some way. Therefore in order to cool the cells in photovoltaic system we integrate a photovoltaic panel with solar air collector. This type of system is called photovoltaic-thermal collector (PV/T) or hybrid (PV/T) and this system has advantage such as it can be used to generate both thermal and electrical energy simultaneously. Cooling of the PV improves efficiency and heat can be used in space heating or for drying system and moreover it is less costly than two separate units. This paper discusses design of a solar PV/T air collector, its performance and exergy and energy analysis of the design.

2. METHODOLOGY

2.1 SOLAR PV/T AIR COLLECTOR CONSTRUCTION

The solar PV/T is constructed using 37 W polycrystalline silicon solar panel. The area of panel is 0.3216 sq. m., enclosed in mild steel box with glass cover at top. The enclosure act as an absorber. A 12V DC fan is used to circulate the air in the system.

Table 1: Technical specification of PV/T system

1	**Solar PV module type**	**Polycrystalline**
2	Maximum power	37 W
3	Voltage at max. power (Vmp)	17 V
4	Current at max. power (Imp)	2.18 A
5	Short circuit current (Isc)	2.30 A
6	Open Circuit Voltage (Voc)	21 V
7	Module area	0.3216 sq. m.
8	D.C. Fan	12V
9	Fluid	Air

Figure 1: Experimental setup of PV and PV/T system

2.2 MEASUREMENTS

Total Instantaneous Global Solar irradiance was measured by using portable Solar Power meter (Tenmars TN-207, Taiwan) with an uncertainty of ± 10%. The ambient temperature and humidity was measured with digital thermo hygro meter. An electrical characteristic of PV and PV/T was measured by using Solar Module Analyzer (MECO 9009). The inlet and outlet air velocity is measured by anemometer. The inlet and outlet temperature of air was measured with digital thermometer. Front side and back side temperature of PV and PV/T panel was measured by using IR Thermometer.

2.3 EXPERIMENTAL PROCEDURE

The experiments were carried out under the meteorological conditions of Bhopal (latitude of 23.16ºN; longitude of 77.24ºE) in India in the month of May 2014 from 10.00 a.m. in the morning to 5.00 p.m. in the evening. Air is used as a coolant in the system with a constant mass flow rate of 0.0142 kg/sec. Wind velocity, Solar intensity, ambient temperatures, relative humidity, open circuit voltage, short circuit current, maximum power, front side and back side temperature of module, fill factor, voltage and current at maximum power, inlet and outlet temperature of air were measured every one hour for both solar PV and solar PV/T systems.

Efficiency describes the performance of the air collector which includes both thermal and electrical efficiency.

Photo Electric conversion efficiency, $$\square e = \frac{I_m * V_m * FF}{GA} \qquad (1)$$

Thermal Efficiency, $$\square th = \frac{mc_p\,(T_{out} - T_{in})}{GA} \qquad (2)$$

Overall Efficiency, $\square_o = \square_{th} + \square_e$ (3)

Energy saving efficiency, $\square_f = \square_e / \square_{power} + \square_{th}$ (4)

Maximum Power, $P_{max} = V_{OC} \times I_{SC} \times FF = V_{mp} \times I_{mp}$ (5)

Exergy Input = Exergy Output + Exergy Loss + Irreversibility

$$n_{ex} = \frac{E_x output}{E_x input} \qquad (6)$$

3. RESULTS AND DISCUSSION

In the present study, a commercial 37W polycrystalline PV module is used to build an integrated PV/T air collector system. The concept of energy saving efficiency has been used to evaluate the energy gain of the PV/T collector. The present test results show that the energy saving efficiency of a hybrid PV/T system exceeds 0.56, which is larger than the efficiency of conventional solar air heating system. The overall performance of PV/T system including electrical and thermal conversion is affected by various factors like Mass flow rate, wind velocity, inlet & outlet air temperature, intensity of solar radiation, ambient temperature, wind speed, orientation of system.

Figure 3 shows the variation of electrical efficiency of PV and PV/T system. The electrical efficiency of PV/T varies between 5.91% and 6.15% whereas electrical efficiency of PV varies between 6.15% and 8.31%. The variation in electrical efficiency of both the system is due to reflection losses in PV/T system.

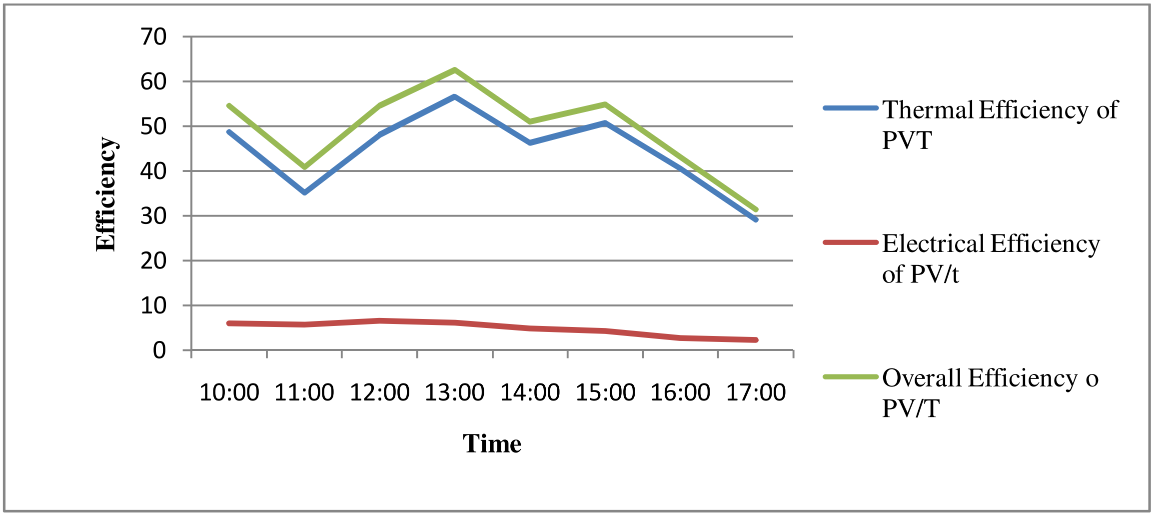

Figure 2: Variation of various efficiency of PV/T

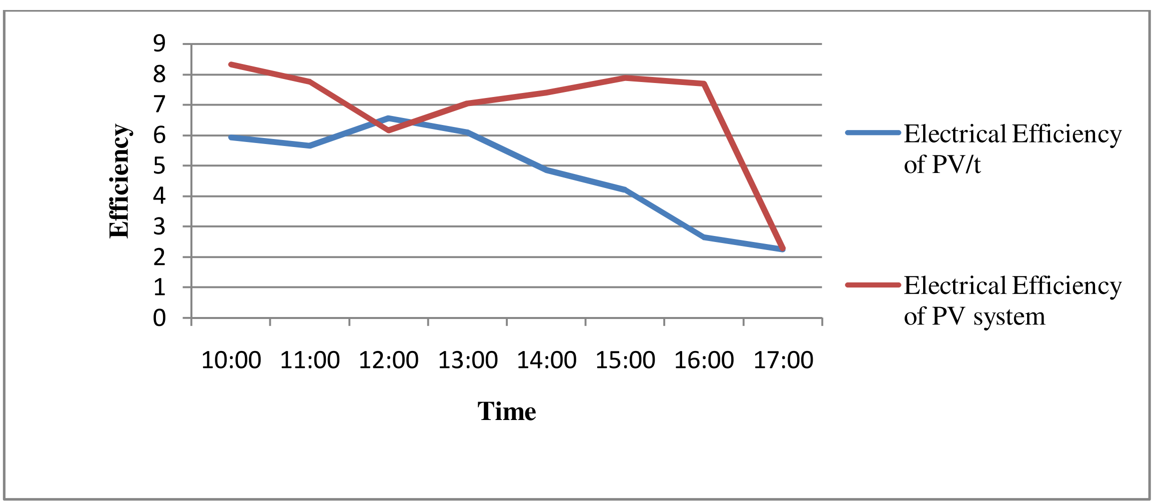

Figure 3: Variation of Electrical Efficiency of PV and PV/T

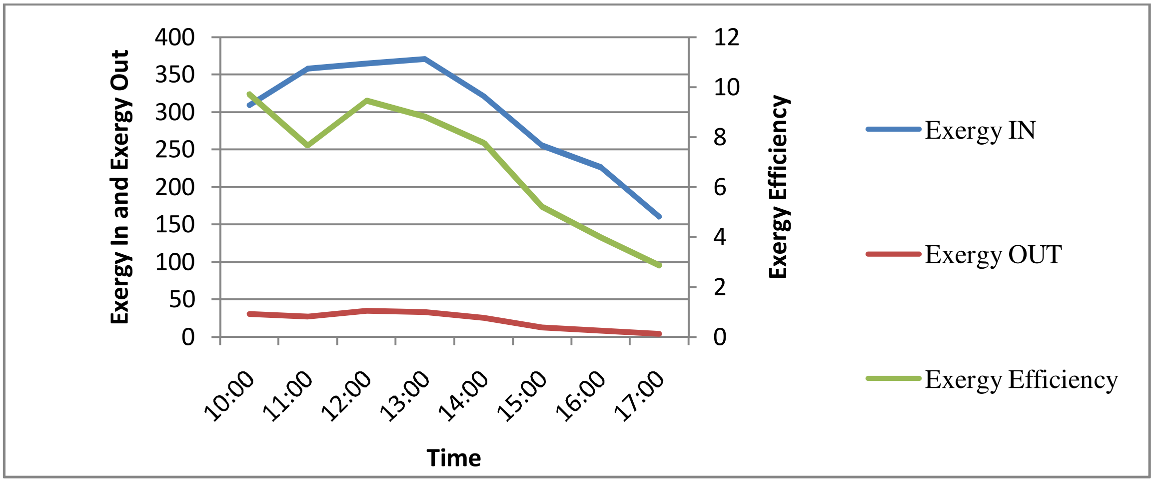

Figure 4: Exergy Efficiency of PV/T

It can be seen that with the constant mass flow rate of 0.0142 kg/sec, the average thermal efficiency was about 44.3% and the temperature rise in flowing air is about 12 ^{0}C. The final temperature of air exceeds 55 ^{0}C. The daily average electrical efficiency of PV/T system was around 4.86% whereas that of PV system was around 6.5%. The average overall efficiency and energy saving efficiency were exceeds 49.1% and 44.48% respectively. The maximum exergy efficiency of PV/T is about9.72% and with average exergy efficiency was exceed 6.97%.

4. CONCLUSION

This article has presented the thermal and electrical performance of the photovoltaic/thermal air collector. A preliminary study of applying this technology in a university building of MANIT, Bhopal has been described. Experiments are conducted with fixed air flow rate of 0.0142 kg/sec and different initial air temperature in the outdoor environment. With the proposed design and operating condition the daily electrical efficiency was about 4.86%, the daily thermal efficiency was about 44.3%, and the total efficiency of the system exceeded 56%. The energy saving efficiency of the PV/T system exceeded 44.4%. The results show that by integrating the solar PV and thermal increases the overall performance of PV/T system than that of employing the PV alone. PV/T application can offer sustainable solution for maximizing the solar energy output from building integrated photovoltaic system. This kind of PV/T system is especially suitable for low temperature applications like hybrid green house, drying or space heating.

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